



500 Rad Test Cell Radiation Safety Interlock System

by Ayo Ayegbusi, Bob Almony, and Marc Litz

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November 2005

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14. ABSTRACT The 500 Rads test cell in building 500 at the Army Research Laboratory (ARL) contains a continuous x-ray source capable of producing lethal radiation levels within 15 seconds. Eight-foot thick walls of concrete are necessary but not sufficient to safeguard personnel. Operating procedures and engineered interlocks are required to ensure safety. This report documents the engineered interlock systems designed for safe operation. These solutions include emergency cutoff switches, warning lights, audible claxons, timing circuits, door interlocks and control circuitry. The electrical schematics, wiring diagrams and operational procedures are described.					
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1. Introduction

This report describes the hardware installed to support a high level of radiation safety. We describe the purpose of each component system; we include parts and model numbers. The inputs to each component are described, as well as the outputs. Some of the wiring existed prior to this system design, and the wiring is laid out in detail so it can be unearthed when repairs or upgrades are required. Other wiring interconnects are new and were added because of the new safety requirements for the continuous x-ray source.

The interlock system described in this document protects experimenters from the harmful effects of gamma radiation produced from a continuous source of X-rays. The Norelco MG300 source was built in 1964. It supports up to 14 mA of current to a maximum potential of 300 kV. The wire wound cathode emits the electron beam which is stopped by the anode. The anode is composed of Tungsten (99%) and Copper (1%). The electrons are stopped by the anode and X-rays are emitted from the surface with a maximum energy of 300 keV, but peaked at 85 keV. Radiation generated in this process is called bremsstrahlung (from the German word for stopping-radiation). The radiation levels from this continuous source present a grave danger. Within 15 seconds, a dose of 500 rads would be delivered to any object in front of the source window. At this dose level, death is expected within 24 hours. The layers of engineered protection designed into this interlock system are warranted based on the risk of exposure.

2. General Description of the Interlock and Area Warning System

Seven systems comprise the radiation safety interlock system. These systems have various functions controlling different parts of the test cell such as the 50-ton door. We discuss each system in further details below. We have included, schematics and pictures to provide a better understanding of these systems. A key feature of the overall system is the auxiliary area personnel warning system that alerts workers in the area prior to and during testing. The alerts include flashing beacons inside the test cell, the bay area and just outside the test cell on top of the 50-ton door. The wire connections from the test cell to the terminal strips in the control room box (figure 1) are unknown because they were laid out during the aurora era. The wires from the terminal strips in the control room to the data room were laid under the floor tiles.

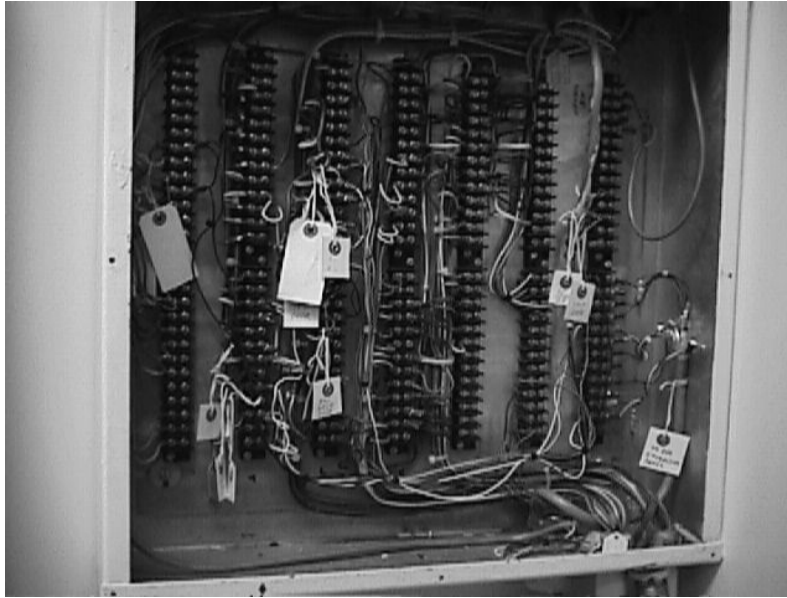


Figure 1. Shows the control room terminal strip box.

The major components of the interlock system, including the location, purpose, as well as the inputs and outputs are described. The circuit in the interlock control panel receives a 24 Vdc supply voltage from the power supply plugged into wall socket 10 behind the panel. This 24 Vdc is connected to terminal strip (TS) 3 pin 1 and is used to supply power to the terminal strips in the control room and to the 50-ton door. The terminal strips in the control room box with power supply connections are the source of power for all the systems. Reference (ground) connections come from TS 1 pin 2 in the interlock control panel board.

We used two types of relays for the interlock system: the 24 Vdc relay and the 110 Vac relay. The 24 Vdc is used to power up the 24 Vdc relay coil (see appendix B, figure B-8 for the 24 Vdc relay layout and picture). 110 Vac is used to power the 110 Vac relay coil (see appendix B, figure B-3 for the layout of the 110 Vac relay. Each relay in the circuit diagrams is labeled as K and then the number. For example, relay 5 will be labeled as K5.

Terminal strips are an essential part of the interlock system. They are long black strips of plastic with connecting screws. An incoming wire terminates at one end of the terminal strip (a screw) which has a connection to the corresponding screw that connects to another system. See appendix A for a complete parts list of all parts used in the interlock system.

3. Control Components and Schematics

This section of the report uses appendix B, figures B-1 and B-2 to describe each of the systems.

3.1 Run Safe Emergency Shutoff

The run safe system is a means for an operator to shut down the x-ray machine from within the test cell to prevent possible exposure to x-rays. There are two run safe boxes in the test cell that provide this emergency shutdown capability. They were placed in their current positions a couple of years ago for the aurora system, but have been modified for shutdown purposes. Run safe box #1 is located between the 50-ton and 110-ton doors, while run safe box #2 is located to the right of the 15 ton door. Figures 2 and 3 show the outside and inside of the run safe box respectively. Their location is clearly labeled on the map of the test cell (appendix D).



Figure 2. Run safe box (outside).

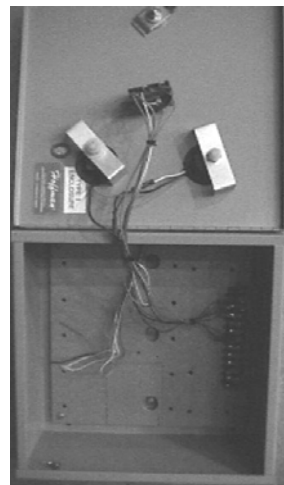


Figure 3. Run safe box (inside).

If an operator is somehow locked in the test cell, the operator reaches for the closest emergency shutdown box located inside the test cell and immediately hits the red button just below the two light-emitting diodes (LED's) that symbolize run (green indicator) and shutdown (red indicator). The red button can be found directly in the center of the emergency shutdown box. The components and circuit diagram of the run safe boxes are identical and can be viewed in appendix B; figure B-5.

The run safe boxes have a 3 pin terminal strip inside the box (can be viewed in figure 2). The terminal strip connects the box indicators and the emergency shutdown button to the control room panel.

Run safe #1 gets its 24 Vdc power from the control room panel's TS 4 pin 8 and its reference (ground) from TS 14 pin 12. The interlock chain that relates the open and close of the switch in

the run safe box when the red button is pushed is controlled by relay 4 in the interlock control panel. Relay 4 is connected to TS 1 pin 2 on the interlock control panel board, which is connected to TS 14 pin 5 in the control room. This pin is connected to the TS in the run safe box pin 2.

Run safe box #2 connections are similar to box #1. It gets its 24 Vdc power from the control room panel's TS 5 pin 6 and its reference (ground) from TS 14 pin 12. The interlock chain pin (pin 2 on the run safe circuit diagram, appendix B, figure B-5) relates to relay 8 in the interlock control panel. Relay 8 is connected to TS 1 pin 10 on the interlock control panel board which is connected to TS 14 pin 9 in the control room panel.

Contacts from relays 4 and 8 are connected to relay 12, the summing relay that interlocks the x-ray machine. If any of these relay contacts become closed, such as when the emergency shutdown button is pressed which closes the switch in the run safe box, the relay drops out of the summing chain. Until the switch is open, interlock system will not work, preventing use of the x-ray machine. When relay 4 and 8 are made, a green LED is lit on the control panel, and when the system is shut off, the red LED is lit.

3.2 Knife Switch

The 50-ton door is the primary access door to the test cell. To prevent entry to the test cell through the 50-ton door during x-ray productions, we installed a knife switch system at the door. The knife switch has both a male and female component, as seen in figures 4 and 5. The knife switch interlocks the 50-ton door when the x-ray machine is on. We also installed an indicator box at the 50-ton door to display when the knife switch is open or closed (see figure 6). The knife switch has two blades in it for contact. The last component of the knife switch system is the beacon that we installed directly above the indicator box at the 50-ton door.

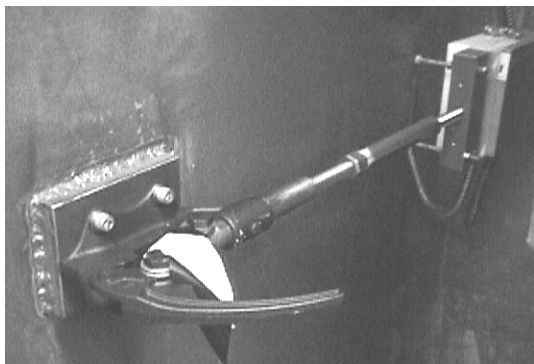


Figure 4. Knife switch (male).

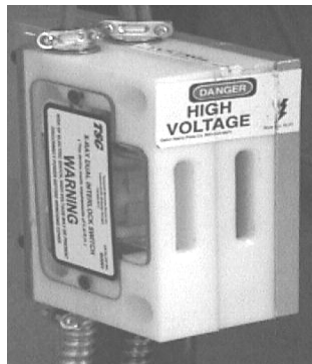


Figure 5. Knife switch (female).



Figure 6. The 50-ton door indicator box.

When the interlock system is turned on at the control panel in the data room, the red light on the indicator box labeled open turns on if the knife switch is open. It stays on until the system is turned off or the switch is closed with the green indicator turning on. If the knife switch was originally closed, the green indicator will turn on.

The circuit diagram of the knife switch system can be viewed in appendix B, figure B-6. The system is supplied with 220 Vac from power outlet 25 in the data room. The power outlet is protected by circuit breaker 25 in the data room circuit breaker box. A special cable for this high voltage was used in connecting the outlet to the Norelco MG 300. The cable was run along the floor of the data room. The 220 Vac coming into the Norelco MG 300 is relayed to the female part of the knife switch with a thick power cable. The cables going to and from the knife switch were run along the back walls of the data room. The two knife blades in the female part of the switch are internally connected in parallel to the incoming 220 Vac supply. When contact is made between the mechanical male part of the knife switch and the female part, 220 Vac is supplied back to the Norelco MG 300 with a thick power cable to provide power for turning on the x-ray machine in the test cell.

Also, the knife switch female has internal micro switches that are supplied with 24 Vdc from the interlock control panel board TS 3 pin 1 and are connected in series with the knife switch and the 24 Vdc relay in the indicator box at the door. We ran the power supply cable along the back wall of the data room to the knife switch. So, when the knife switch is made, the micro switches form a series connection with the relay in the indicator box and provides 24 Vdc to the relay.

There is a terminal strip in the indicator box with three pins that connect the relay inside the box with the wires coming in and out of the box. The incoming 24 Vdc is connected to pin 1, and that pin is connected to the green indicator. So anytime the 24 Vdc power comes to that pin, its connection to the relay closes the switch in the relay and the green indicator turns on, indicating that the knife switch has been closed. At the same time, the second switch on the relay is also connected to the incoming 24 Vdc and the switch closes and returns the voltage to relay 10 on the interlock control panel board within the same cable that brought the 24 Vdc to the knife switch micro switches. But when the micro switches are not made, the relay switch on pin 1 on the terminal strip stays open and keeps the red indicator on, indicating that the knife switch is open.

When all the relays that sum into relay 12 are made, relay 12 makes. One of the by-products of relay 12 being made is for pin 3 on the relay to provide the beacon with 110 Vac through the wires we ran along the walls of the data room to the beacon at the 50-ton door. The 110 Vac comes from the normal closed pin 3 of the relay, which is connected to TS 4 pins 1 and 2 on the interlock control panel board, where pin 1 is neutral and pin 2 is hot. The supply voltage to this pin comes from wall outlet 10 in the data room that supplies the interlock control panel board with 110 Vac.

Another byproduct of summing relay 12 being made is that the switch on pin 1 of the relay closes and takes the 220 Vac that is connected to its normally closed pin 1 and relays it over to pin 1's normally open pin which is connected back to the Norelco MG 300. Only now can the x-ray machine be turned on.

The last of the byproducts of summing relay 12 being made occurs when pin 4 of the relay takes its incoming 24 Vdc from the interlock control panel board power supply and relays it over to the green indicator on the front of the interlock control panel. The green indicator, as labeled, indicates that the interlock system has been completed and that the Norelco MG 300 can be turned on to start the x-ray production.

The 24 Vdc relayed to relay 10 on the interlock control panel board from relay 1 in the indicator box at the 50-ton door makes relay 10. Relay 10 summarizes the knife switch system and is one of the relays that sum up in series to relay 12 (as seen on figure B-2, appendix B). Pin 1 output of relay 10 is connected to TS 4 pin 8, which is connected to pin 4 of relay 12. So when relay 10 is made, the connections make relay 12 pin 4 and relay 12 is a step closer to being made.

3.3 Key Box Reset Switch

The main part of the interlock system is the key box reset switch. The key reset switch is located inside the test cell at the right corner of the back wall. The key reset switch ensures that no one is left inside the test cell and that no one enters the test cell before the 50-ton door is closed and the knife switch made.

The key box reset switch system is made up of a sonalert box, an external power supply to the right to supply 24 Vdc from the 110 Vac power supply in the test cell, and an indicator on the outside of the box to indicate when the timer is turned on. The internal components of the key box reset switch system are the reset switch that the key hole on the external part of the box is connected to, two 110 Vac circular relays, one TS and a 5.5 min timer system. The external and internal components can be viewed below in figures 7 and 8 respectively.

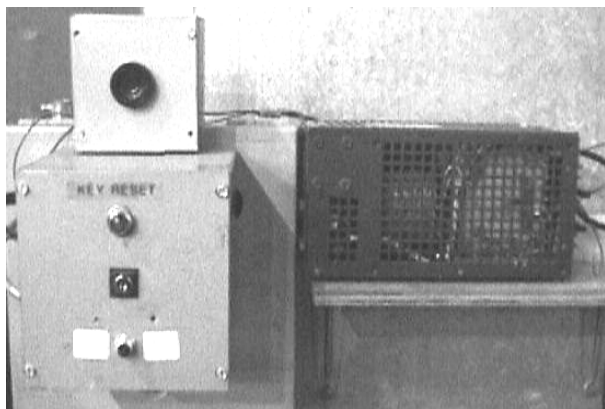


Figure 7. Key box reset switch.

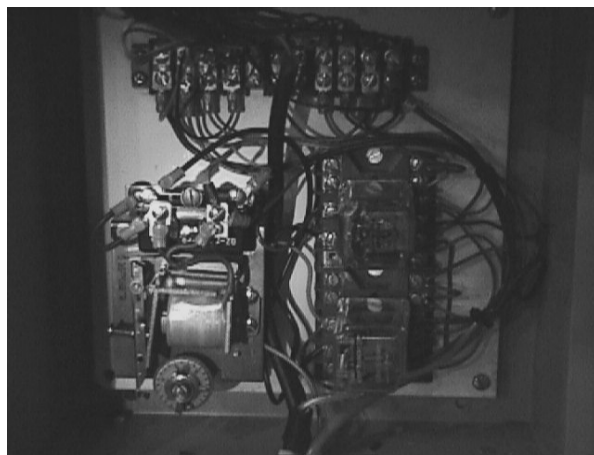


Figure 8. Key box reset switch (internal).

After the operator has cleared the test cell and is ready to start x-ray production, the operator walks to the key box reset switch, inserts a key and turns it right to turn on the 70 second timer in the box. As the timer counts down to zero, the sonalert speaker on top of the box beeps on each count. Also, the operator has to clear the test cell, exit through the 50-ton door and make sure the knife switch is made in 70 seconds. If the operator does not accomplish this task in 70 seconds, the whole process will have to be redone because, without completing the task, the operator can't start x-ray production figure 5 shows the key reset box. Appendix B contains a schematic diagram of the key reset circuit.

The circuit diagram in appendix B, figure B-3 describes the wire connections between the components of the system. The 24 Vdc from the power supply is connected to pin 1 on the TS, while the 24 Vdc return is connected to pin 11 on the TS. The 110 Vac from the panel outlet on the side of the wall next to the key reset switch has the neutral connected to pin 2 on the TS, while the "Hot" is connected to pin 4 on the terminal strips. When the key is used to turn the reset switch, it creates a connection between the 110 Vac and relay 1. The 110 Vac makes the relay and all the normally open contacts of the relay become connected to the normally closed

contact. Basically, the switches in the relay become closed when making a connection. The 110 Vac power coming from the reset switch connection closes the switch at pin 1 of the timer and makes a connection from there with the relay 2, which then makes relay 2. Relay 1 relays over the 24 Vdc voltage connected to its pin 3 to turn on the green indicator on the front of the box. Relay 2 relays over the 24 Vdc voltage connected to its pin 1 to start the beeping countdown by the sonalert box. There is also a connection of the 24 Vdc voltage from pin 2 of relay 2 to the auxiliary area warning control box. After 70 seconds, the switch at pin 2 of the timer opens up and stops the timer. Lastly, pin 3 from relay 2 is connected in series to the 50-ton door knife switch with a cable that runs along the walls of the test cell to the knife switch. With relay 2 made, the switch at this pin closes and as soon as the 50-ton door is closed, the relay in the indicator box at the 50-ton door can now be made.

3.4 Auxiliary Area Warning Control Box

The area warning control box controls the beacon and horn just above the box inside the test cell, the beacon in the bay area, and the test cells air handling system. It also has a red button switch on the side to test the horn and the beacon in the test cell. The switch is used for warm – up tests before x-ray production. The box warns anyone inside the test cell, at the 50-ton door and in the bay area that x-ray production will be commencing shortly and when x-ray production is on-going. The beacons stay on as long as the system is still on.

The only external components are the red button switch (S1) on the left side of the box used for warm-up proceedings and a switch (S2) on the right side of the box for turning on the air handling system. Inside the box there is a TS, one 24 Vdc relay, and three 110 Vac relays, and the two switches that are connected to the external button and switch (see figure 9).



Figure 9. Picture of the area warning control box.

Relay 1 (K1) is the 24 Vdc relay and it receives its 24 Vdc power supply from TS pin 5, which is connected to the 24 Vdc output coming from the key reset switch system. This 24 Vdc voltage only comes from the key reset switch because it turns on and makes the relay. Pin 1 of relay 1 is connected to TS pin 1, which has a connection to a 110 Vac voltage supply coming from circuit breaker 12 in the circuit breaker panel. The circuit breaker has a 9 A breaker. So, when K1 is made, its pin 1 connects the 110 Vac voltage to S2, which is already switched on to connect to K2 and K4. This 110 Vac makes K2 and K4. K2 turns on the beacon in the test cell through its pin 1 that is connected to TS pin 7, which in turn is connected to the beacon through a wire run up along the wall. The beacon in the test cell can also be turned on when the red button on the side of the box is pushed inward. There is a direct connection from the end of the red button switch to TS pin 7. K3 pin 1 is used to turn on the beacon in the bay area through the connection to TS pin 9 which goes out through the back wall into the bay area. The bay area beacon only turns on when K3 pin 1 contact is made. K4 is connected to the red button switch. When the button is pushed, it allows K4 to receive the 110 Vac connected to it and all the K4 contacts are made, which are all connected to the horn. So, the horn makes a loud noise while the operator has the button down, the only way the horn comes on. All the contacts of K4 are connected to TS pin 13 and then pin 13 is connected to the horn by a wire run up along the wall to the horn. Pins 2, 4, 8, 10, and 14 are all the 110 Vac neutral connections. Pin 6 is the 24 Vdc ground connection. Pins 3 and 4 are connected to pins 1 and 2 respectively and are then connected to the key reset switch box to provide that system with 110 Vac power. A schematic diagram of the Auxiliary Area Warning circuit can be viewed in appendix B, figure B-4.

3.5 Power Interrupt System

The Norelco x-ray box has a circuit breaker attached to the side of it. It acts as a power interrupt when there is any variation in the input voltage. Another way of interrupting the power is switching off circuit breaker 25 in the test cells circuit breaker panel.

3.6 Test Cell Access Doors

There are 3 access doors to the test cell. These doors are marked on the map of the test cell. The 15-ton and 100-ton doors are bolted and locked up with a key from within the test cell. The test cell cannot be accessed from the outside using these doors, but according to regulations, they can be used to exit the test cell during emergencies. They are not for frequent use. There are micro-switches at the top of the 15-ton and 100-ton doors. These micro-switches were placed in their current positions for the old aurora system. The wires that connect the 15-ton and 100-ton door micro-switch and the control room TS are part of the wires that were initially in place with the old system.

The 15-ton door micro-switch gets its power from TS 5 pin 10 in the control room. TS 5 pin 10 is connected to the 24 Vdc power supply on the interlock control panel board (TS 3 pin 1). The status of the micro-switch is relayed back to relay 2 (K2) on the interlock control panel board through connections to TS 5 pin 12 in the control room box, which is connected to TS 14 pin 3

also in the control room box, which is connected to TS 3 pin 4 on the interlock control panel board in the data room. TS 3 pin 4 has a connection to Relay 2 (K2) that gets the status of the micro-switch and uses the status to make or unmake the contacts in the relay. If K2 pin 2 is made, the wire that goes from pin 2 to the green indicator turns on the indicator on the front of the interlock control panel, indicating that the 15-ton door is closed. But if the K2 pin 2 is not made, the red indicator on the front of the interlock control panel stays on, indicating that the 15-ton door is open.

The 100-ton door micro-switch gets its 24 Vdc power from a direct connection through the control room box to the interlock control panel board TS 3 pin 1 in the data room. The status of the micro-switch is relayed back to relay 3 (K3) on the interlock control panel board through connections to TS 14 pin 3 in the control room box, which is connected to TS 1 pin 1 on the interlock control panel board in the data room. TS 1 pin 1 has a connection to Relay 3 (K3) that gets the status of the micro-switch and uses the status to make or unmake the contacts in the relay. If K3 pin 2 is made, the wire that goes from pin 2 to the green indicator turns on the indicator on the front of the interlock control panel indicating that the 100-ton door is closed. But if the K2 pin 2 is not made, the red indicator on the front of the interlock control panel stays on, indicating that the 100-ton door is open.

The 50-ton door used to access the test cell was already discussed under the knife switch system. It can be opened from the outside, but there are no control systems to open it from the inside.

3.7 Interlock Control and Status Panel

The control panel is located in the data room (see appendix D). It is a tall panel behind the Norelco MG 300 control box (see figure 10). Only a section of the panel is used for the interlock system. The interlock control and status panel has two parts to it. The first part is the board inside of the panel (see figure 11) and the second part are the visual indicators and the switch on the front of the panel as seen in figure 12.



Figure 10. Interlock control and status panel tower with Norelco MG 300 at the base.

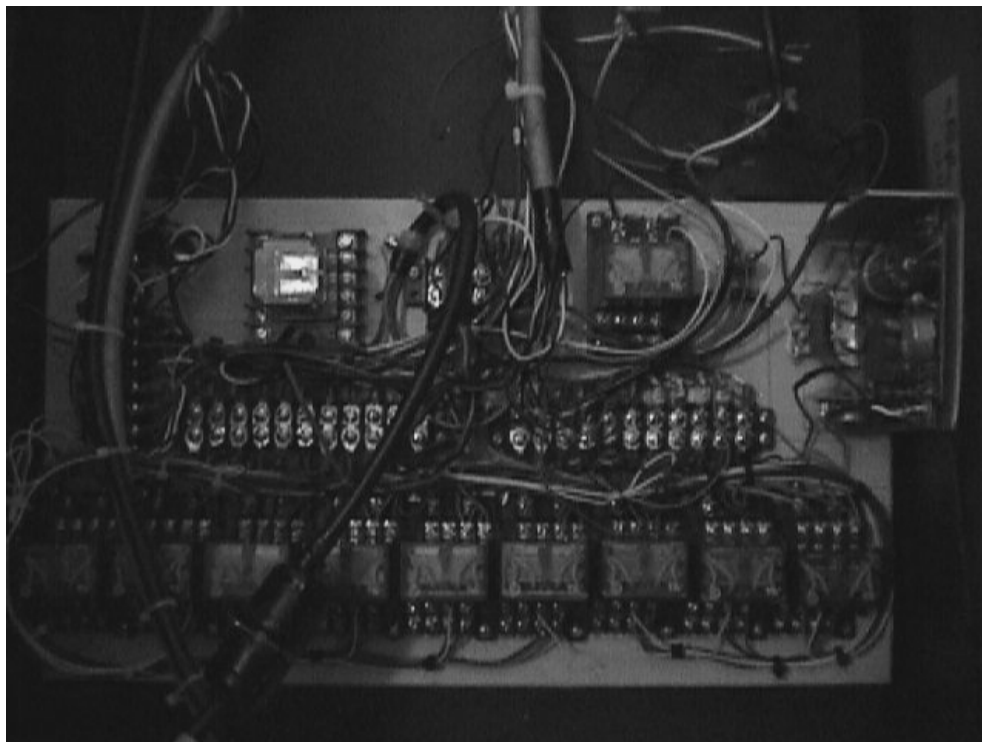


Figure 11. Interlock control panel and status panel (inside) showing the layout of the board.

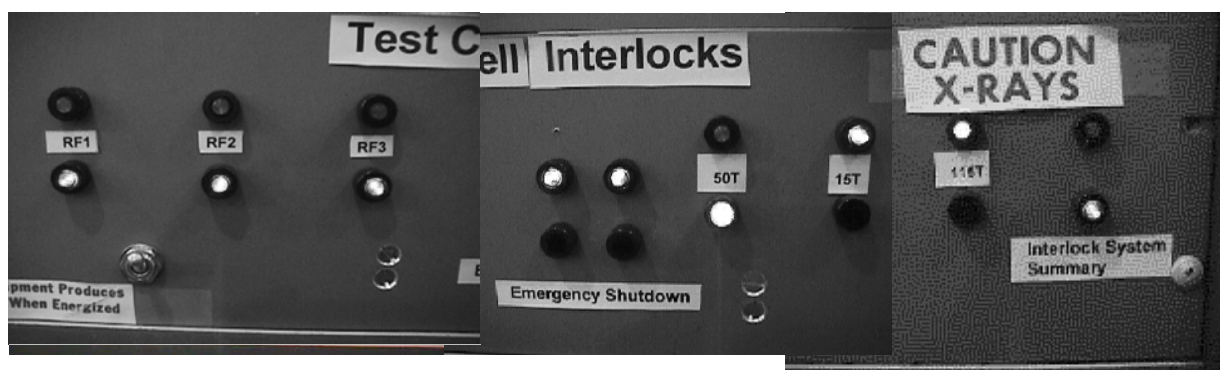


Figure 12. Interlock control and status panel (front).

The board on the inside of the panel houses the relays that connect to all the other systems, the terminal strips used to connect the relays to the system, and a 24 Vdc power supply. The layout of each part's location on the board is attached in appendix B figure B-7. The 24 Vdc power supply is on the side of the board, while K1 to K10 are the 10 24 Vdc relays that connect to and control the other systems. The TS are labeled TS-1, 2, 3, and 4. One end of the terminal strips goes out to the systems, while the other end goes to each system's respective relay. K11 is a spare 110 Vac relay installed for future purpose. K12 is the summing relay, where contact pin 1 from relays 1, 2, 3, 4, 8, and 10 all connect in series to it. Appendix B, figure B-2 shows what system each relay controls and the relays that sum up to relay 12 (K12).

The switch on the front of the panel is used to turn on the system and it is located on the bottom left corner of the panel. When the switch is turned off, all the indicators go off, but when the switch is turned on, the indicators display the status of each system at that time. Each system whose status is displayed on the front panel has two indicators, a green and a red indicator. There are nine system status indicators on the front panel.

From the left, the first 3 are status indicators for the RF doors inside the test cell. Their red indicators are always on because they are not for radiation purposes so there is no need to make sure they are closed. The next sets of indicators are for the two run safe emergency shutdown boxes. Their green indicators are usually on when the system is turned on. The red indicators only turn on when the emergency shutdown button has been pushed in at the run safe boxes. When the button is reset at the boxes, the green indicator comes back on. The next three set of indicators are for the test cell access doors. The 50-ton door is the first from the left and it displays the status of the 50-ton door at every point in time. When the knife switch at the 50-ton door is made, the green indicator turns on; while the red indicator turns on once the knife switch is opened. The 15-ton and 100-ton doors are to the right of the 50-ton door indicators and their green indicators are usually on because these doors have been locked. If one of these doors or both opens, the red indicator will turn on indicating that the door is not closed. The last sets of indicators are for the interlock system summary. These indicators indicate the status of the summing relay. When all the systems are ready and the summing relay (relay 12) becomes made, the green indicator turns on; otherwise, the red indicator will turn on. The green indicators for the run safe emergency shutdown boxes and the test cell access doors have to be on before the green indicator for the interlock system summary can turn on. If any one of these systems have their red indicators on, the interlock system summary red indicator will turn on.

The right side of the diagram in appendix B (figure B-2) shows the relays that control the indicators for each system. For example, K2-2 means relay 2 pin 2 is connected to the 15-ton door indicators.

4. Summary

In December 2004, we started to design a radiation interlock system to provide safety for upcoming experiments using a continuous x-ray source. The design of the seven subsystems has been described in sufficient detail to initiate repairs, upgrades or normal maintenance.

The first tests with the continuous x-ray source were carried out in March 2005. The radiation safety interlock system has operated successfully for the last six months.

Reliability was considered in the design of this system; failure of an interlock could prove deadly. As a result, a daily checklist examining each level of operation is documented daily (see appendix E). Adhering to the daily checklist and following the SOP is essential in maintaining ARL safety standards and radiation licensing.

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Appendix A. Parts and Equipment List

A complete list of parts used in making the interlock system is listed below:

Parts	Where Used	Function
LAMPS		
Chicago Miniature Type 1819 24 V, 0.04 A Lamps	Run/Safe Boxes Key Reset Box	ON-OFF 70 second Timer "ON"
Dialco 28 V, 0.04 A Green & Red Lamp Mfr's#: 5073917	Interlock Control Panel	"Go" & "Stop" Indications
Dialco Lamp Sockets Mfr's#: 508-7538-504	Interlock Control Panel 50-ton Door, Open & Closed Status Box	Sockets for Dialco Lamps Open or Closed Indications
SWITCHES		
Toggle 110 V 10 A General Purpose STSP	Interlock Control Panel	Power 110 V to Panel
Momentary Normally Closed Grayhill Type 4002	Key Reset Box	Reset Switch
Interlock Switches Micro Switch	All Interlock Doors	Opens Interlocks When Door is Opened
Key Switch 3A-125 Vac, 2 A- 250 Vac, L173	Key Reset Box	Starts 70 second. Timer
Mushroom Emergency "Stop"/Go 22 mm Push Button Operator Allied Stock# 676-7650 Contact Block Inc, INO Allied Stock# 676- 7686	Run/Safe Boxes	Emergency Stop of X-ray machine
TIMER		
Eagle Signal Part# HD504A622 5.5 min, 120 V, 60 Hz, SW 15 A, 125-250 Vac, 1/8 hp (125 Vac, 1 A) 1/4 hp (250 Vac, 1/4 A)	Key Reset Box	70 second. Timer
Circuit Breaker 9 A	Area Warning Control Box	Circuit Protection
Fuze 2 A	Interlock Control Panel	Circuit Protection
Fuze Holder 5 x 20 mm	Interlock Control Panel	For 2 A Fuze
RELAYS		
Guardian 4PDT Series A410 24 Vdc Coil	Interlock Control Panel Area Warning Control Box Side of Beacon Control box	Interlock Status and Control Beacon Control Turn on Geiger Counter
P&B Relay KRP 14AG, 115 V 50 – 60 Hz	Key Reset Box Beacon Control Box	Timing Circuit Turn on Beacons

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Appendix B. System Schematics and Drawings

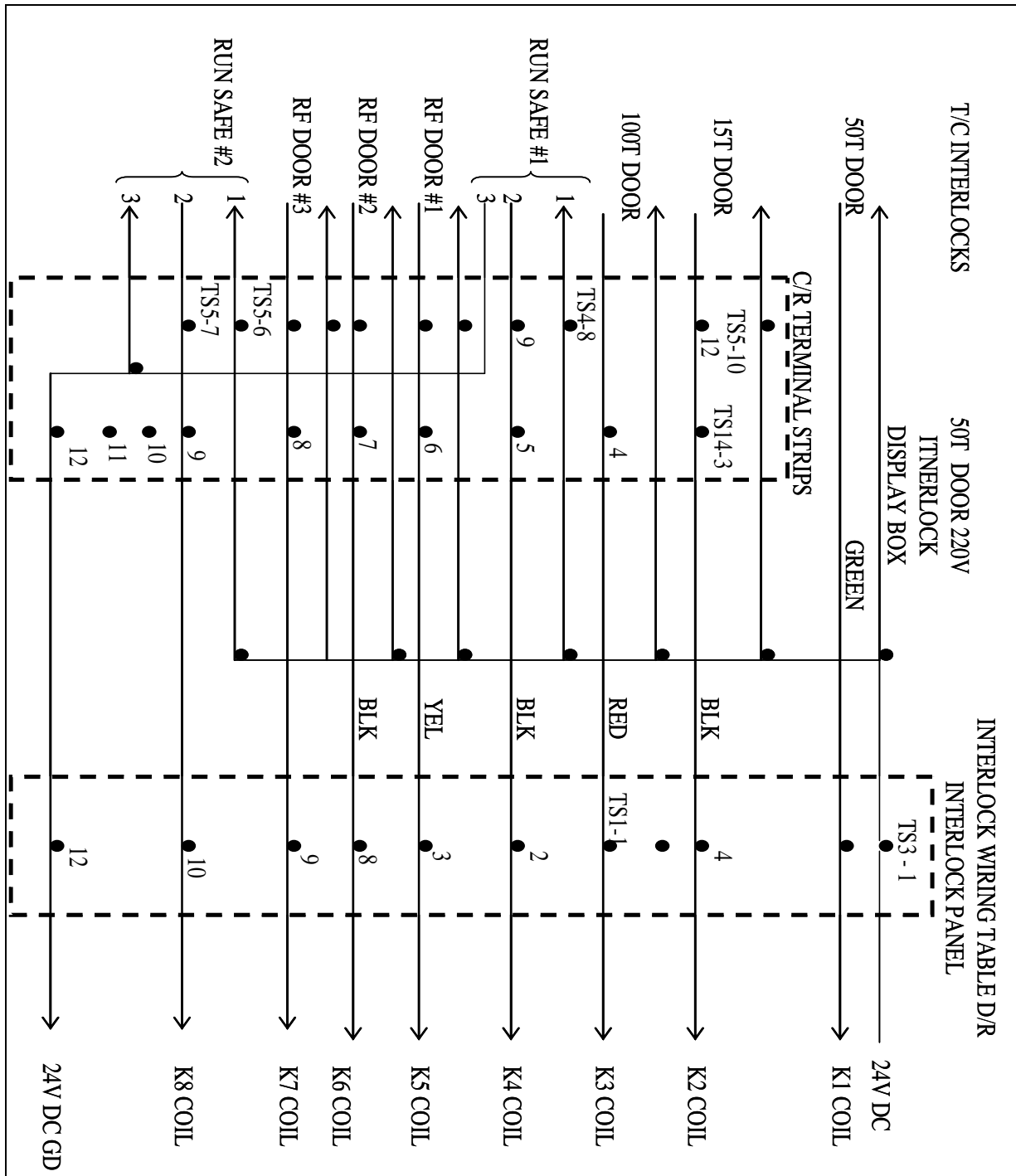


Figure B-1. The wiring table of the data room interlock panel. It shows the connections between relays 1 to 8 and their respective components.

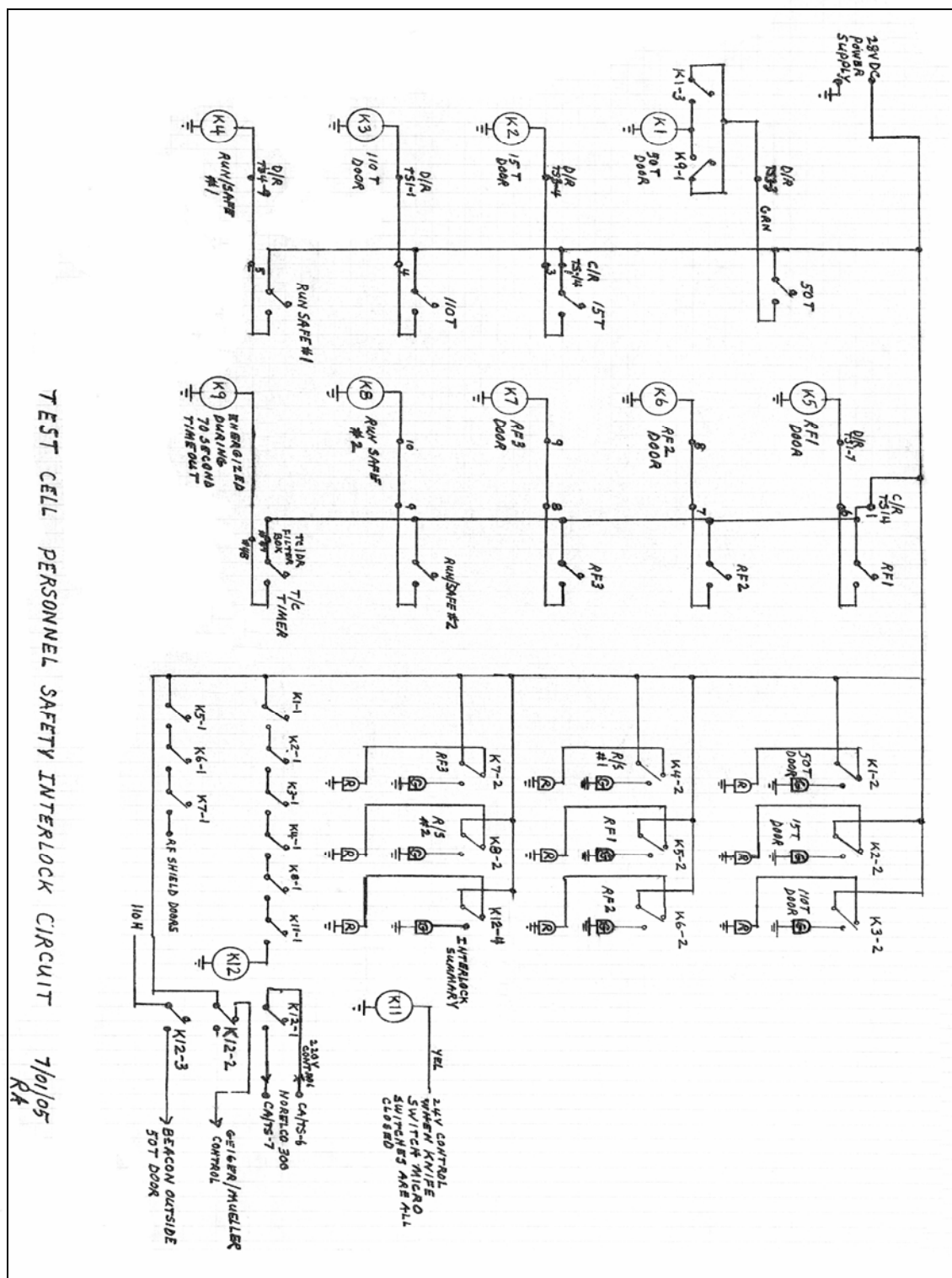


Figure B-2. Picture of the interlock system circuit diagram. It captures the connections of all the relays and indicators. It is an overall circuit diagram of the interlock system.

KEY BOX CIRCUIT

The diagram illustrates the electrical wiring for a key box system. It features a 24VDC power source (TS-1) and a 110VAC power source (COIL 2 & 10). The 24VDC source is connected to a 24VDC RET. (11) and a 110VAC H. (4). The 110VAC source is connected to a 110VAC N. (2). The circuit includes a KEY SWITCH (K1-1) and a KEY SWITCH (K2-1). The KEY SWITCH (K1-1) is connected to the 24VDC source and the 110VAC H. (4). The KEY SWITCH (K2-1) is connected to the 110VAC H. (4) and the 110VAC N. (2). The KEY SWITCH (K2-2) is connected to the 24VDC source and the 110VAC H. (4). The KEY SWITCH (K2-3) is connected to the 110VAC H. (4) and the 110VAC N. (2). The SONALERT is connected to the 110VAC H. (4) and the 110VAC N. (2). The TIMER (I1) is connected to the 24VDC source and the 110VAC H. (4). The RELAY (K1) is connected to the 110VAC H. (4) and the 110VAC N. (2). The RELAY (K2) is connected to the 24VDC source and the 110VAC H. (4). The RELAY (K3) is connected to the 110VAC H. (4) and the 110VAC N. (2).

110 VAC RELAY

COIL 2 & 10
COMMON 1C-1
NO 1B-3
NC 1A-4

2C-6
2B-7
2A-5
3C-11
3B-9
3A-8

TO 50T
DOOR INT.
CIRCUIT

24VDC CONTROL
VOLTAGE TO AUX AREA
WARNING CONTROL BOX

19

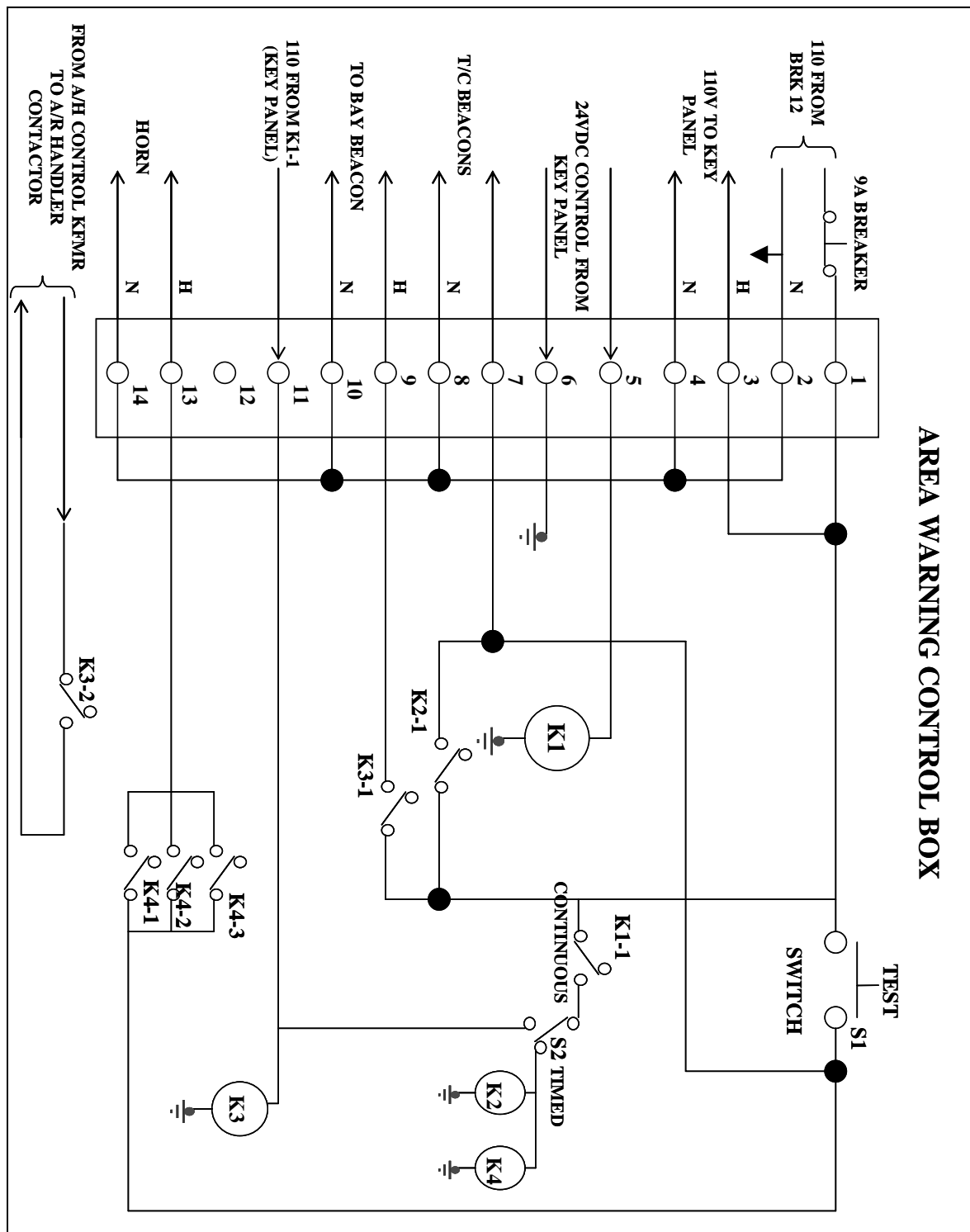


Figure B-4. The area warning control box circuit diagram. It shows connections of the relays that control the area warning beacons and the ventilation during x-ray production.

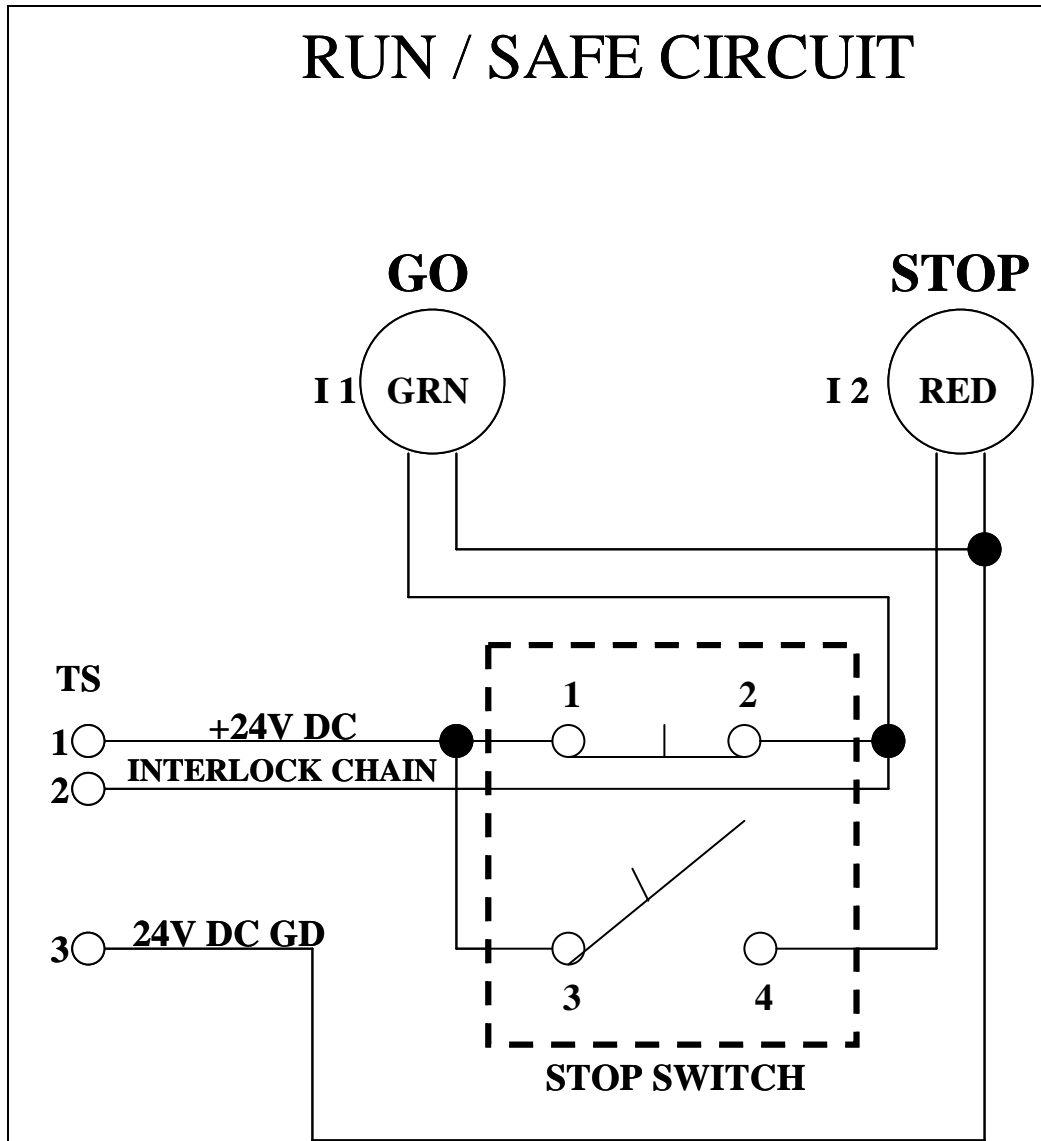


Figure B-5. Run/safe box circuit diagram. It has two LED's that indicate the status of the system.

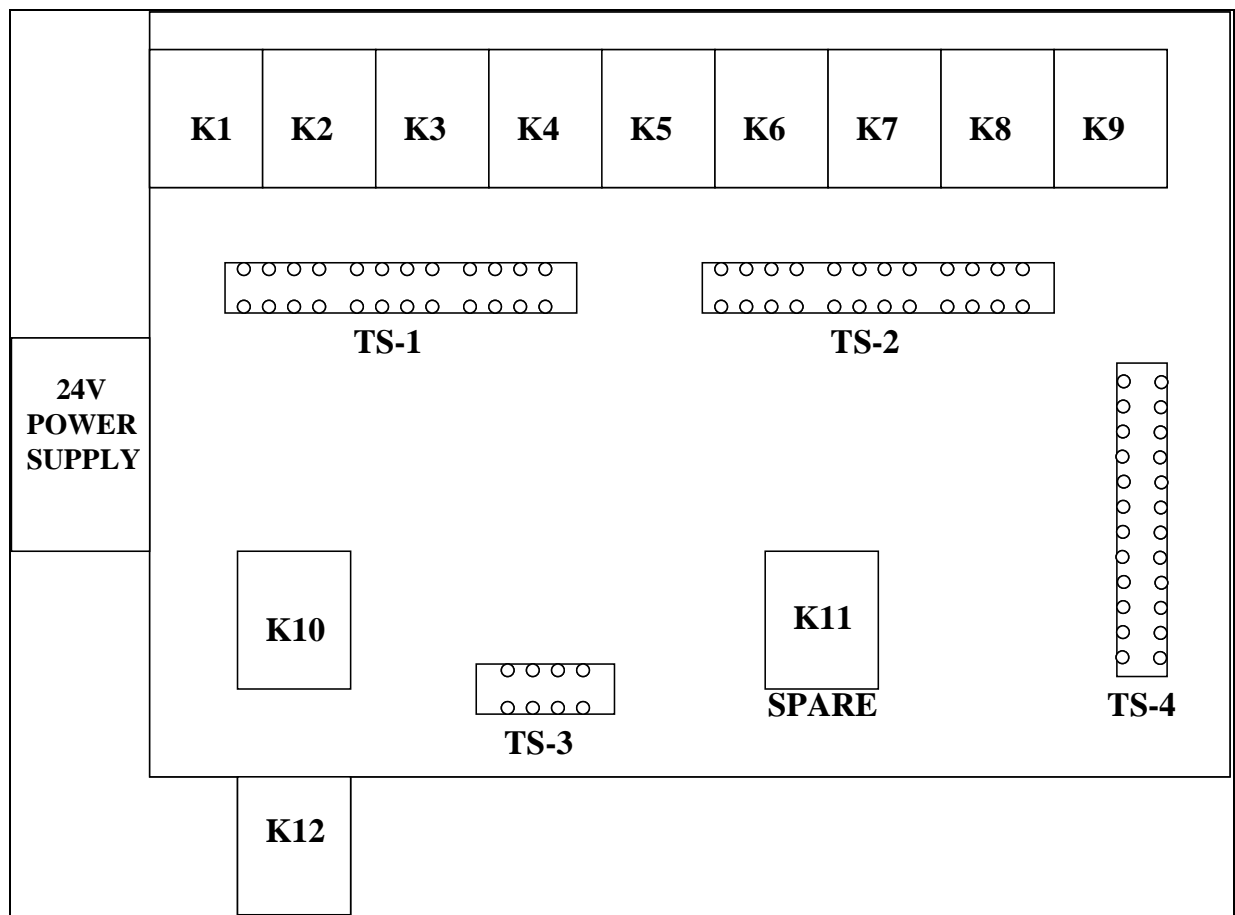


Figure B-7. Layout of control panel board. It shows all the relays and the terminal strips used to connect them. It also has a spare relay (#11) for future applications. The 24 V power supply provides the whole system 24 V where needed.

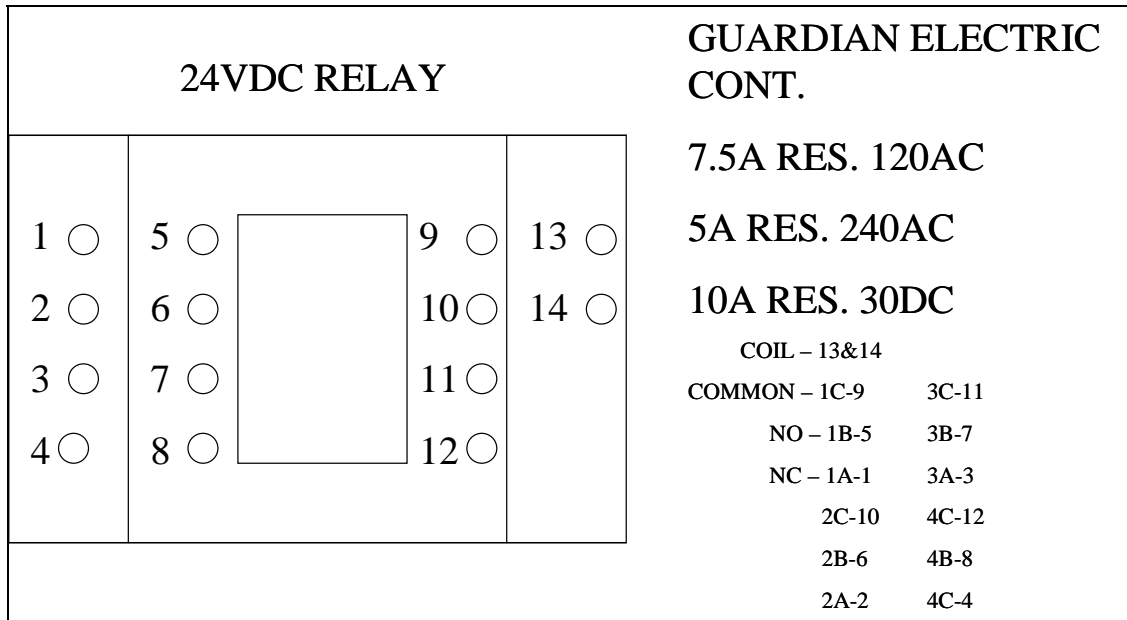


Figure B-8. Layout of a single relay. Approximately 20 of the 25 relays used in the system are of this configuration.

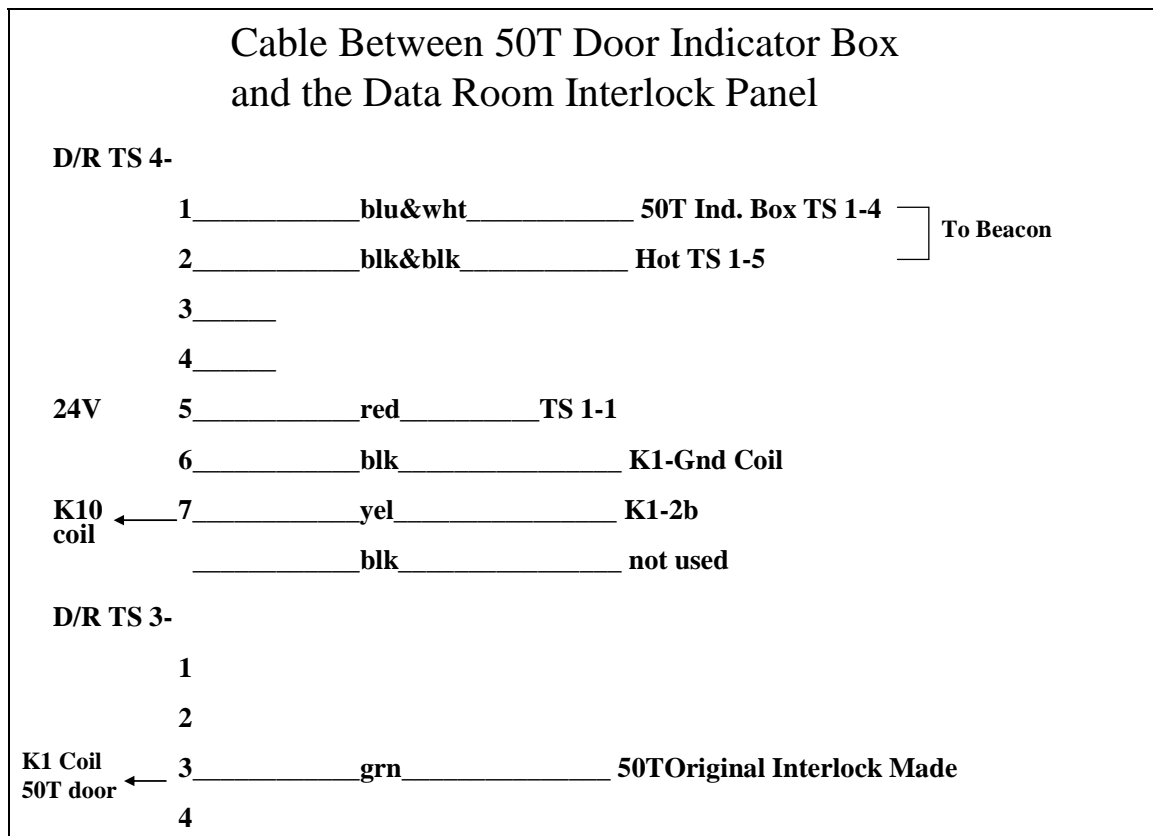


Figure B-9. 50-ton door indicator circuit diagram. It shows the connections between the relay in the indicator at the 50-ton door and the data room interlock control panel.

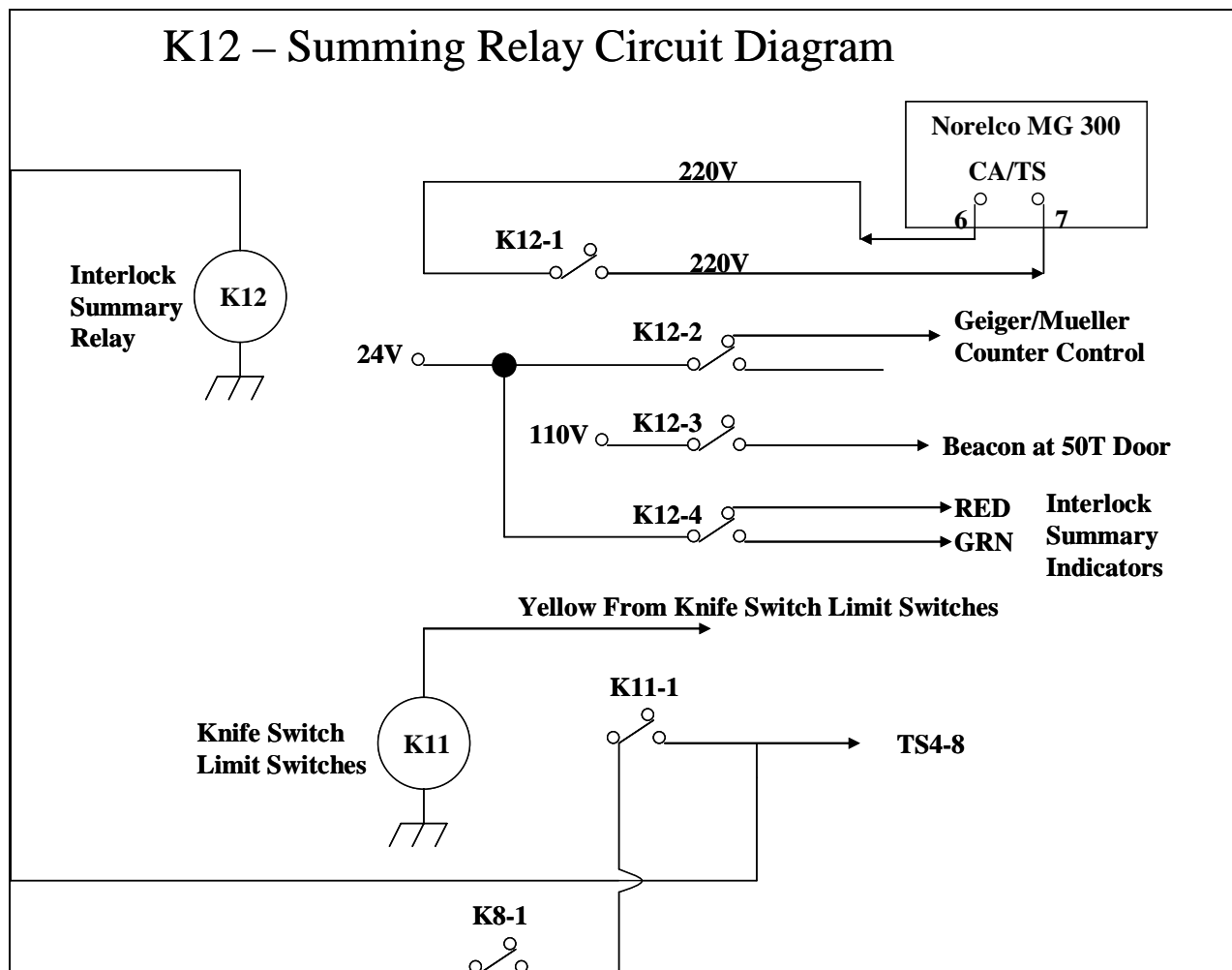


Figure B-10. Summation circuit diagram. All system relays sum up to this relay. All relays must be made before machine power is applied through this relay.

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Appendix C. Standard Operating Procedure

STANDING OPERATING PROCEDURE

TITLE: Building 500 Test Cell X-ray Operations

DIVISION/BRANCH: Sensors and Electron Devices Directorate, Directed Energy and Power Generation Division, Directed Energy Branch, ARL-SE-DE

LOCATION: Building 500, Test Cell

No deviations from this Standing Operating Procedure (SOP) will be permitted. Whenever the approved methods in this SOP must be changed, the SOP must first be revised and approved in writing by the Safety Office and Radiation Control Committee.

Supervisory personnel will assure that all personnel involved with this SOP have been trained properly and instructed in its provisions, and attest to this by causing them to affix their signatures on page 2.

A copy of this SOP will be posted at the X-ray operating console at all times.

Branch Chief: _____ Date _____
Dr. Stephen Bayne

Division Chief: _____ Date _____
Dr. Edward Shaffer

APPROVED:

Radiation Safety Officer Date

Radiation Safety Committee Date

Team Leader, ARL Safety Office Date

Appointment of Operators:

The following individuals have successfully completed Radiation Worker training from the Safety Office. They have also been trained on the design and proper operation of all radiation safety shielding, interlocks, warning, and control systems. They have also been reviewed and approved by the Radiation Safety Committee to serve as an Operator for X-ray operations in the building 500-test cell.

Approved Operator Date

Branch Chief Date

Approved Operator Date

Branch Chief Date

Operator and Visitor Signatures:

The following signature acknowledges that I have read and understand the SOP entitled Building 500 Test Cell X-ray Operations. My signature further acknowledges that I understand that Bldg 500 test cell X-ray hazards are dangerous and that I will follow the precautions and procedures specified in this SOP:

Name

Date

1. Statement Of Work: This SOP will regulate the operation of X-ray devices in the building 500-test cell. These X-ray sources are high level and are dangerous enough to require approval by the ARL Director through the issuance of an Army Radiation Authorization (ARA).

2. Hazards Involved:

a. X-radiation. X-ray tubes are used to irradiate small radioactive samples. The intensity of the X-rays inside the test cell is dangerous, and greatly exceeds the personnel protection standards. For example, at 300 kV and 10 mA, the X-ray level in the beam is about 900 rem/hr at 1 meter from the tube. This level qualifies as a Very High Radiation Area, and THIS LEVEL IS DANGEROUS. A lethal dose of about 300 rem could be received in only 20 minutes.

Elsewhere in the test cell at locations that are not in the primary X-ray beam, the X-ray level would be “rems” per hour. Even these areas would qualify as a “High Radiation Area”.

b. High Voltage. The X-ray tube is powered by very high voltages. Contact with any component of the X-ray high voltage power supply could be fatal. This includes the feed voltage, the rectified primary voltage, the rectifying capacitors, and the high voltage from the step-up transformers. The primary voltage is also carried through extension cords to the doors leading into the test cell. The plugs on the extension cords may be used to disconnect the voltage when a door is opened, or blade switches may be installed on the doors to disconnect the voltage. This will terminate X-ray production when the door is opened. Disassembly of a blade switch or extension cord plug could result in exposure to a dangerous voltage.

c. Ozone. X-ray absorption in the air in the test cell can produce ozone. Ozone is a gas that can irritate the respiratory tract and eyes.

3. Protection Standards/Limits:

a. X-radiation.

(1) Radiation Worker. The annual limit for exposure to a Radiation Worker is 5 rem/yr. In the beam at a distance of 1 meter from the tube, this would be exceeded in only 20 seconds. THIS IS A DANGEROUS X-RAY SOURCE THAT REQUIRES ALL PERSONNEL TO BE CLEARED FROM THE TEST CELL.

(2) Unrestricted Area Limits. The limit for unrestricted areas is .002 rem/hr not to exceed 0.100 rem/yr. Exposure below these levels is considered insignificant. In the beam, these levels would be exceeded in less than 1 second. Even at locations not in the beam, these levels could be exceeded in minutes.

b. High Voltage. Voltages exceeding 24 volts are considered dangerous. Contact with any component at 24 volts or higher is unacceptable.

c. Ozone. The workplace standard for exposure to ozone during light work is 0.1 ppm, with peak levels not to exceed 0.2 ppm for more than 2 hours. Levels as low as 0.04 ppm can be detected by smell.

4. Safety Controls

a. Engineering Controls

(1) X-ray Shielding. The doors, walls, and roof of the test cell are constructed of 3-10 feet of concrete/earth shielding. The dimple plate hole in the bay wall has been shielded with 16 inches of concrete. The doors are provided with overlaps, stepping, and trenches to prevent X-rays from scattering under and around the doors. The shielding will reduce radiation levels outside the test cell to below the unrestricted area limits of 2 mrem/hr, not to exceed 100 mrem/yr everywhere except for the dimple plate opening shield where these limits could be slightly exceeded (the x-ray beam will therefore always be directed towards the back wall of the test cell). Penetrations through the test cell walls and roof are specially designed to prevent X-ray streaming. Significant X-ray levels outside the test cell are therefore not expected.

(2) Interlock Circuit. The test cell doors are equipped with 24-volt interlock switches. These switches are part of the 24-volt interlock circuit, which prevents X-ray production when a door is open, and terminates X-ray production if a door is opened during X-ray production. The 50-ton door, which will serve as the normal entrance to the test cell is also equipped to disconnect the 220-volt primary voltage when opened. This is accomplished by a plug or blade switch that automatically disconnects the 220-volt primary voltage when the door is opened. The remaining doors to the test cell, although included on the 24-volt interlock circuit, will also be locked closed, with the key kept by the operator.

(3) Interlock System Reset Switch. To ready the 24-volt interlock system for X-ray production, the interlock system reset key-switch located in the test cell must be activated. Once it is activated, the operator has 70 seconds to leave the test cell and close all the doors. If the doors are not closed within 70 seconds following activation of the reset switch, the interlock system will not be satisfied, and the process will have to be repeated. This serves as a method to ensure the operator enters the test cell, clears it of personnel, and secures the interlocked doors without enough time passing to allow someone to enter the test cell between the reset and the securing of the doors. To ensure the X-ray tube cannot be powered during the 70-second time period the doors may be open, the interlock-reset key must be located on the same key ring as the X-ray tube control key. To ready the 220-volt interlock circuit, all doors must be closed, and the 220-volt switches and or plugs must be connected.

(4) Warning Klaxon/Light. A klaxon and warning lights have been installed inside the test cell to warn personnel when an X-ray tube is powered. This warns anyone accidentally in the test cell so they can strike an EMERGENCY SHUTDOWN button, preventing or terminating X-ray production. A warning light will also be installed outside the 50 ton door leading into the test cell and outside the dimple plate to warn approaching personnel when X-rays are present in the test cell.

(5) Emergency Shutdown Switches. Two switches are provided in the test cell to immediately terminate/prevent X-ray production. In the event someone was accidentally in the test cell and heard the klaxon sounding and/or saw a warning light flashing, he/she could strike an EMERGENCY SHUTDOWN button to immediately terminate/prevent X-ray production.

(6) Warning Signs/Labels. All doors leading into the test cell must be equipped with a sign stating “GRAVE DANGER - VERY HIGH RADIATION AREA WITHIN”. Two signs must be posted inside the test cell stating “GRAVE DANGER – VERY HIGH RADIATION AREA DURING X-RAY USE”. The X-ray tube and operating console must be equipped with labels warning “Caution - X-rays Produced When Energized”. A sign will be erected near the X-ray source to remind operators that the X-ray beam can only be directed towards the back wall of the test cell.

(7) Ventilation. The test cell is equipped with a fresh air supply and return that will remove the ozone produced during irradiation. Following long term irradiations, five or ten minutes or more may be necessary following irradiation to allow the ventilation system to clear the ozone from the test cell.

(8) Unattended X-ray Irradiation. Unattended X-ray irradiation for over-night irradiations is permitted only if all doors leading into the test cell are locked in the closed position, and the key is held by the operator. This precaution and the other radiation safety features of the test cell meet the requirements of paragraph 5.2, ANSI 43.3, Installations Using Non-Medical X-ray and Sealed Gamma-Ray Sources, Energies Up To 10 MeV, for unattended operation.

b. Procedural Controls

(1) Authorized Operators. Only personnel that have successfully completed radiation worker training through the Safety Office and have been trained in the safe and proper operation will be permitted to operate the X-ray source. Operators must also be individually appointed by the Branch Chief on page 2 of this SOP. Furthermore, operators are required to read this SOP and sign page 2 acknowledging understanding and vowing compliance.

(2) Access Control. Only authorized operators will have access to the X-ray interlock circuit reset key, which will be kept under the control of an Operator. When the key is not being used, it will be kept in the possession of an operator. Keys to any locked doors leading into the test cell will be kept by the operator. A copy will also be provided to the building supervisor for access in the event of an emergency. If an operator provides a set of door keys to the facility supervisor, he/she must instruct the facility supervisor on the power down procedure for the tube. In this way, entrance will not subject the tube to the abrupt shock of the interlock circuit shutdown. The facility supervisor will be instructed on how to power down the X-ray tube before entering the test cell to avoid

(3) Postings. This SOP and the authorizing Army Radiation Authorization (ARA) must be posted at the X-ray operating console at all times.

(4) Radiation Dosimeters. All operators and other personnel present while X-rays are being produced shall wear radiation dosimeter issued by the Safety Office (Michael Borisky, 301-394-6310).

(5) Repair and Maintenance. In the event of malfunction, only a qualified X-ray repair technician can correct the malfunction. Repair or maintenance by ARL personnel is forbidden. Following any repair or maintenance that involves the X-ray shielding, shielding doors, or warning/interlock system, contact the Radiation Safety Officer for re-survey before X-ray operations resume.

(6) System Check. Each day, prior to the start of X-ray operations, the operator will test and document that all 24-volt safety devices are functioning properly. This includes the interlock system reset circuit, each 24-volt door switch, the 24-volt emergency stop buttons, the klaxon, and the warning lights. **DO NOT POWER THE X-RAY TUBE TO CONDUCT THESE TESTS.** Testing the 220-volt switches is not necessary, but they must be inspected each day to ensure they are properly fastened and tight. A checklist will be formulated to help the operator conduct and document these daily checks.

(7) Waiting for Ozone Clearing. Following X-ray irradiation, it may be necessary to wait for five or ten minutes or more for the ventilation system to clear any ozone produced in the test cell. This will be particularly true for long-term irradiations. If ozone is smelled upon entering the room, leave the room, shut the door, and allow an additional 10 minutes as necessary until ozone is no longer smelled upon entering.

(8) Beam Direction Reminder. Shielding calculations show that if the beam is directed towards the dimple plate opening shield, the radiation level on the other side could slightly exceed the unrestricted area limits. The radiation level presented would not be hazardous, but in accordance with the ARL As Low As Reasonably Achievable policy, would be unjustified. **The beam will therefore only be directed towards the rear wall of the test cell, i.e., the wall with the 100-ton rolling door. A sign will be conspicuously posted to remind operators to only point the X-ray beam towards the rear wall.**

(9) Housekeeping. The X-ray machine shall not be used unless the housekeeping in the test cell is good enough for the operators to easily and accurately detect the presence of personnel in the test cell. This will facilitate clearing personnel in preparation for an irradiation.

5. Sequence Of Operations.

a. Before the first irradiation of the day, test the 24-volt interlock system reset, switches, klaxon, warning lights, and EMERGENCY SHUTDOWN buttons, by completing the daily checklist.

b. Operator will announce across the building 500-wide intercom system his intent to prepare the test cell for X-ray production.

c. Operator removes the key ring from the X-ray control console, enter the test cell and clear the test cell of all personnel.

d. Once all personnel have left, activate the interlock system reset key, immediately exit the test cell and secure all doors.

- e. Begin the X-ray irradiation.
 - f. If for any reason a door is opened or an EMERGENCY SHUTDOWN button is pressed, the entire sequence must be repeated.
 - g. Following the irradiation, allow 5 minutes for ozone purging before re-entering the test cell.
 - h. Using a calibrated survey meter or detector, re-enter the test cell. If an odor of ozone is smelled upon entering, exit the test cell, close the door, and allow an additional 10 minutes for ozone clearing.
6. Emergencies: In the event of an emergency, immediately stop generation of the X-rays and terminate power to the X-ray tube. In the event of a safety system failure, or accidental or suspected personnel exposure, stop operations immediately and contact the Radiation Safety Officer at 301-304-6310 or 410-278-6354.

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Appendix D. Map of Test Cell and Data Room

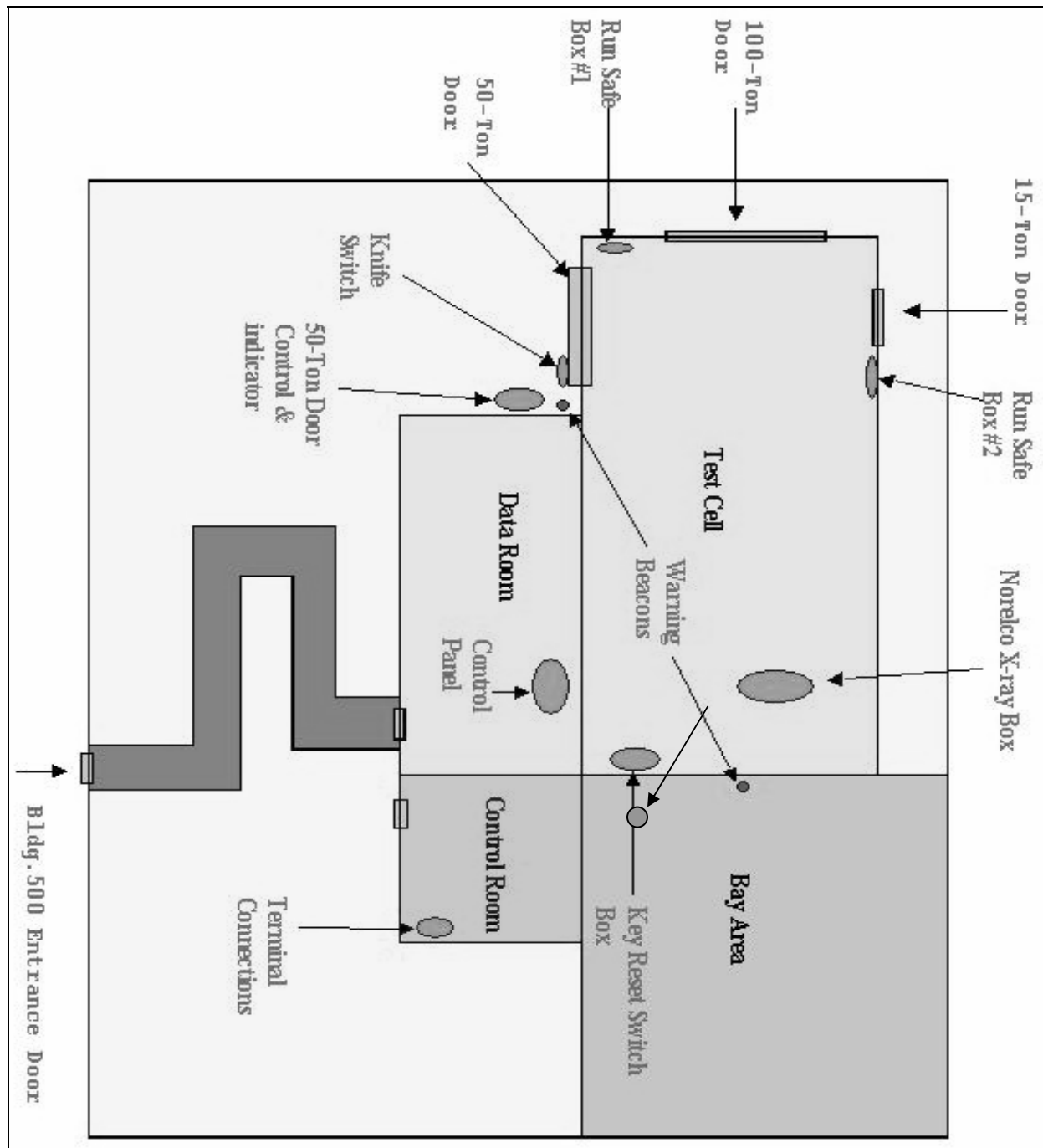


Figure D-1. Map of Bldg. 500's test cell and control room area. This map points out where every interlock system is located.

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